QuikSCAT Geophysical Model function for Hurricane Wind and Rain

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Abstract –**The SeaWinds scatterometer on the QuikSCAT spacecraft has been operating since August 1999 to provide global mapping of ocean winds. The ocean surface winds from the QuikSCAT scatterometer have been shown to be accurate, except for precipitating and extreme high wind conditions. It is known that the QuikSCAT scatteroemter winds typically underestimate the strength of tropical cyclones and overestimate the wind speed for low to moderate wind speeds (3-10 m/s) under rainy conditions. We examined collocated QuikSCAT radar data and SSM/I rain rate to assess the effects of rain. It is shown that the QuikSCAT $\sigma 0$s increase with increasing rain rate for low and moderate wind speeds (<15 m/s) and has an opposite trend for hurricane force winds (>32 m/s). It is also shown that the QuikSCAT $\sigma 0$ modulation by the wind direction is reduced by the rain. The results are consistent with the existing QuikSCAT wind speed biases and characteristics of wind direction solutions at the presence of rain. Our results suggest that the rain rate can be introduced as an additional modeling parameter for the Ku-band scatterometer model function to reduce the wind retrieval bias resulting from the rain for adverse weather conditions.**

I. INTRODUCTION

Scatterometers are a microwave radar specifically designed to make high precision measurements of the normalized radar cross section (σ_0) of ocean surfaces. Because of the sensitivity of σ_0 to ocean surface roughness, which is directly influenced by the surface wind velocity, it is feasible to estimate the ocean surface wind velocity from microwave scatterometer observations. The relationship between the ocean σ_0 and the surface wind velocity is usually described by a geophysical model function (GMF). An empirical GMF is currently used for the processing QuikSCAT data. The SeaWinds scatterometer on the QuikSCAT spacecraft has been operating since August 1999 to provide global mapping of ocean winds. The ocean surface winds from the QuikSCAT scatterometer has been shown to be accurate, except for precipitating and extreme high wind conditions.

For extreme high winds, it was postulated by [5] that three major error sources are limiting the performance of scatterometers: 1) Deficiencies of the geophysical model function for high winds, 2) Effects of heavy rain on the microwave attenuation and the roughness of sea surfaces, and 3) Wind gradient in the sensor footprint near the eye wall where the maximum wind speeds are expected. To make a direct assessment of the ocean $_0$s for high winds, numerous aircraft scatterometer flights were conducted over tropical cyclones [1,2,6]. With these sets of aircraft data, modified model functions have been proposed, but there was still a systematic underestimate of wind speeds for above 30 m/s winds [4]. The effects of rain and wind gradient have apparently not yet been properly considered in the retrieval algorithms for spaceborne scatterometers.

The effects of rain on Quikscat winds were found to be severe for low and moderate wind speeds (<10 m/s). There could be a positive wind speed bias of 5 to 10 m/s. In addition, rain tends to make the wind direction solutions retrieved from Quikscat data point along or across the spacecraft nadir track. A rain flag has to be applied to the QuikSCAT winds. Although rain events are infrequent, they could be associated with significant weather phenomena. It is important to know whether scatterometer winds can be improved under rainy conditions.

Rain has three effects on the scatterometer radar measurements. It attenuates the radar signal. It introduces volume scattering. It also perturbs the water surfaces and consequently influences the radar backscatter from the surface. It appears that the attenuation and volume scattering effects can be accurately modeled by microwave radiative transfer equations, as demonstrated by the radar precipitation results from the Tropical Rainfall Measuring Mission [8]. The expected rain attenuation is about 0.6 dB/km at Ku-band frequencies for 10 mm/hr rain rate [9]. In contrast, the surface perturbation effects are very hard to quantify. Laboratory measurements indicated that the surface roughness generated

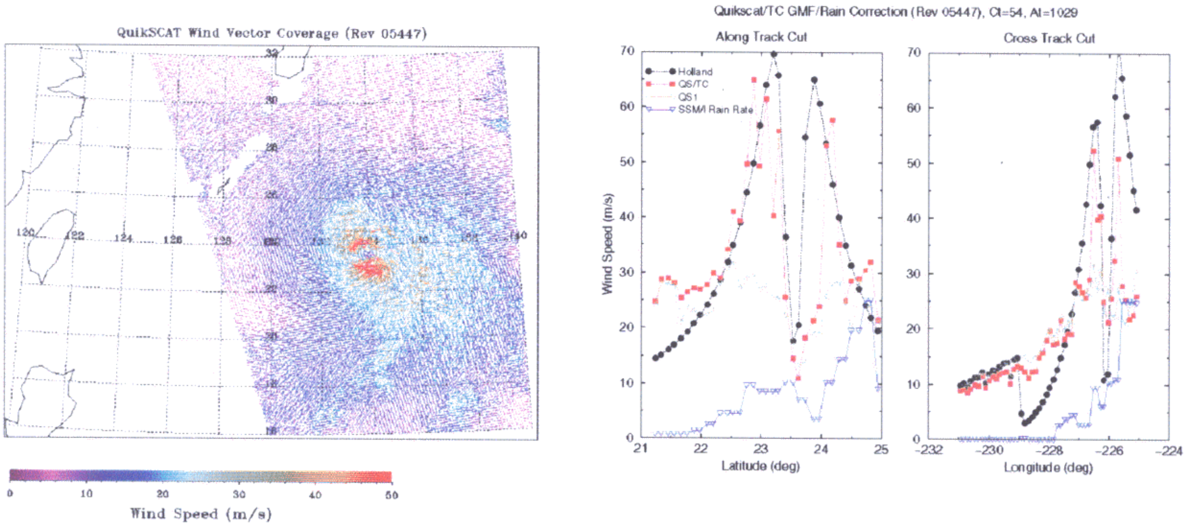

Fig. 1 Quikscat winds for typhoon Kirogi on July 5, 2000. (a) The Quikscat vector wind field with color-coded wind speed and (b) The wind speed profiles along and across the spacecraft track through the eye wall. The Quikscat wind speed from QS GMF and without rain correction is in green and the improved wind speed is in red. The blue curve indicates the SSM/I rain rate in mm/hr.

by raindrops can enhance the radar scattering by a few dB at 14 GHz and 40° incidence angle [10,11,12]. It was suggested that the ring waves and stalks generated by raindrops are dominant scattering features with the former being more important at the incidence angles of 30°-40°. A power law dependence of σ0s on rain rate was proposed [11]. However, it is unclear whether the laboratory results are applicable to open ocean conditions.

II. QUIKSCAT σ0 FOR HIGH WIND AND RAIN

To study the effects of rain on scatterometer wind retrieval, a semi-empirical approach was undertaken by [7]. For hurricane winds, the Quikscat σ_0's with the collocated Special Sensor Microwave/Imager (SSM/I) rain rate and the winds from an empirical hurricane wind model [3] were analyzed for 58 Quikscat passes of 7 Atlantic hurricanes in 1999 [7]. It was shown that the QuikSCAT σ_0s appear to increase quasi-linearly with the wind speed. The slope decreases with increasing rain rate. It was also demonstrated that a modified geophysical model function together with the correction of rain effects using the SSM/I rain rate allowed the improvement of wind observations for hurricane Floyd 1999. We have applied the analysis by [7] to the QuikSCAT data acquired from about 50 passes of 8 hurricanes in 2000. The 2000 data confirmed the observations described in [11].

For lower than 20 m/s wind speed, the QuikSCAT σ0 data were correlated with the wind from the National Center for Environmental Predictions and the SSM/I rain rates. It is shown that the QuikSCAT σ0s increase with increasing rain rate for low and moderate wind speeds (<15 m/s) and has an opposite trend for hurricane force winds (>32 m/s). It is also shown that the QuikSCAT σ0 modulation by the wind direction is reduced by rain. The results are consistent with the existing QuikSCAT wind speed biases at the presence of rain and characteristics of wind direction solutions.

III. QUIKSCAT WIND FOR TYPHOON KIROGI

We applied the linear regression model reported in [7] together with the collocated SSM/I rain rate to process the QuikSCAT measurements of typhoon Kirogi in 2000. Typhoon Kirogi was a super typhoon with its maximum strength reaching about 140 knots in July 4 and 5, 2000. The estimated QuikScat wind field of typhoon Kirogi is illustrated in Fig. 1, which also plots the wind speed along two orthogonal cuts through the center of typhoon. The green curves, the results from the QuikSCAT GMF without rain correction, significantly underestimate the strength of typhoon Kirogi. As shown, at 20:31UT of July 5, 2000, the maximum wind speed of Kirogi recorded by Quikscat (red curves) was about 60 m/s, comparable to the one of 70 m/s (140 knots) reported by best track analyses.

IV. SUMMARY

To determine the feasibility of improving the QuikSCAT estimates under rainy and/or high wind conditions, the data from QuikSCAT radar operating at 13.4 GHz (Ku-band) have been analyzed to examine the relationship of Ku-band σ0 of ocean surface with rain rate and wind speed. For lower than 20 m/s wind speed, the QuikSCAT σ0 data were correlated with the wind from the National Center for Environmental Predictions and the rain rate from the Special Sensor Microwave/Imager (SSM/I). For extreme high wind speeds (>20 m/s), we analyzed the data from tropical cyclone passes in the Atlantic and Pacific in 1999 and 2000. The results suggest that the rain effects can be reduced by introducing the rain rate as a parameter in the scatterometer GMF and for processing.

The Quikscat results from the analyses of Pacific typhoons and Atlantic hurricanes have demonstrated significant potential of scatterometer observations for the applications to tropical cyclone research. Further analysis is needed to determine the limitations of the scatterometer winds for tropical cyclone modeling.

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